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(54) **Automatic control system and method for air separation units**

(57) A method for automatically setting a target production level for at least one air separation unit in a network of air separation units. Each air separation unit has a plurality of field elements and at least one regulatory controller associated with one of the field elements, and has an energy usage level corresponding to a level of production. The method includes receiving a production level requirement for the network of air separation units and generating a production target level for at least one of the air separation units which minimizes and/or optimizes the sum of the ASU energy usage levels. The ASUs then can automatically ramp the plant production to the appropriate production target levels via the use of advanced process control (multivariable process controllers and/or advanced feedforward controllers), advanced regulatory control, and regulatory control means. The control system includes a receiver for receiving inputs from the at least two air separation units, and a supervisory controller which generates production target levels for sending to each air separation unit, the production target levels being representative of a network production target level and a network energy usage level.

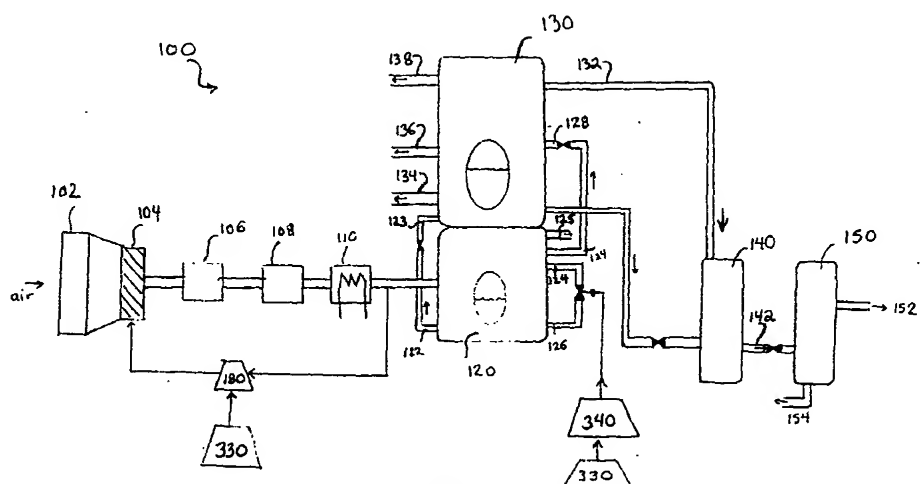

FIG. 1

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Description

[0001] This application is related to, and claims priority from, U.S. Provisional Application 60/207,775, which was filed in the United States on May 30, 2000.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] This invention relates to a control system, and specifically, to a control system for a network of air separation units.

Background Information

[0003] Cryogenic Air Separation Units (ASUs) have been used to produce oxygen, nitrogen, and argon, and other gases, as desired. An ASU generates gases by refrigerating air and distilling it, so energy is the primary production cost of an ASU.

[0004] Air Separation Units may be integrated into a network, with a centrally managed pipeline network for transporting the output gases to customers.
An ASU pipeline network manager's primary objective is to minimize global network energy consumption while maintaining contractually required volumes and pressures along the network. This is accomplished by adjusting operating parameter targets at the various ASUs feeding the pipeline. Traditionally, determining operating parameter targets for the various ASUs has been accomplished by human operators at an Operations Control Center (OCC). ASU plant operators, in turn, strive to adjust their ASU to meet their operating parameter targets from the OCC in an efficient manner. Of course, the nature of human interaction in this process minimizes the prospect of consistent optimal control of the network.

[0005] It would be desirable to provide a method for optimization of ASU production levels which is less dependent on human operators, and for controlling the ASUs so they operate in the most efficient manner at their target production levels.

SUMMARY OF THE INVENTION

[0006] In an exemplary embodiment of the invention, a method is provided for automatically setting a target production level for at least one air separation unit in a network of air separation units, each air separation unit including a plurality of field elements and at least one regulatory controller associated with one of the field elements, and having an energy usage level corresponding to a level of production, the method including: receiving a production level requirement for the network of air separation units, and generating a production target level for at least one of the air separation units which minimizes the sum of the network energy usage levels.

[0007] In another exemplary embodiment, the method may also include changing the level of production of an air, separation unit until it is about equal to the generated production target level for the air separation unit. In another exemplary embodiment, an advanced process controller for setting a setpoint associated with at least one of the plurality of field elements may be used to change the level of production of an ASU. The advanced process controller may be an advanced feedforward controller. The advanced process controller may also be a multivariable predictive controller. In another exemplary embodiment, both an advanced feedforward controller and a multivariable predictive controller may be included. In another exemplary embodiment, the method can also include monitoring the advanced process controller (APC) to determine whether it is operational, and to what extent the controller is operational (e.g., identify an APC service factor), and further can include identifying a non-operational advanced process controller.

[0008] In another exemplary embodiment, the method can also include controlling at least one of a plurality of field elements in an air separation unit. A model based adaptive controller can be used to control the at least one of a plurality of field elements in an air separation unit. In another embodiment, a model free adaptive controller can be used to control the at least one of a plurality of field elements in an air separation unit.

[0009] Another exemplary embodiment of the invention includes a control system for automatically setting the target production level for at least one air separation unit in a network of air separation units, each air separation unit including a plurality of field elements and having at least one production level and an energy usage level corresponding to the production level; the control system comprising: a receiver for receiving inputs from the air separation units; and a supervisory controller for generating a production target level for at least one of the air separation units.

[0010] In another exemplary embodiment, the control system can receive inputs which include the energy usage levels and levels of production of the air separation units. In another exemplary embodiment, the control system can also include an advanced process controller for changing the production level in an air separation unit until it is about equal to the generated production target level for the air separation unit. In another exemplary embodiment, the advanced process controller can generate a setpoint associated with at least one of the plurality of field elements in the ASU.

[0011] In another exemplary embodiment, the control system can also include at least one regulatory controller for controlling the at least one field element of an ASU. Regulatory controllers can be, for example, PID controllers, HIC controllers, gap controllers, or deadband controllers.

[0012] In another exemplary embodiment, a network of air separation units comprises: at least two air sepa-

ration units, each air separation unit including a plurality of field elements and having at least one production level and an energy usage level corresponding to the production level; a pipeline, at least two air separation units in fluid communication with the pipeline; a control system for automatically setting the target production level for the at least two air separation units, the control system in control communication with the at least two air separation units and including a receiver for receiving inputs from the at least two air separation units, and a supervisory controller for generating data representative of a network production target level and a network energy usage level for the air separation units.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Other objects and advantages of the present invention will become apparent to those skilled in the art upon reading the following detailed description of the referred embodiments, in conjunction with the accompanying drawings, wherein like reference numerals have been used to designate like elements, and wherein:

FIG. 1 is a schematic of an exemplary Air Separation Unit for use in an exemplary embodiment of the invention.
FIG. 2 is an illustration of a network of Air Separation Units in which the invention can be used.
FIG. 3 is an illustration of a hierarchy of controllers for a network of Air Separation Units, according to an exemplary embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0014] Air separation units separate components of air into gas and liquid outputs, including, for example, oxygen, nitrogen, argon, and other gases, as desired, by cooling, liquefying, and distilling air. One or more of numerous ASUs can be used and controlled according to the present invention. By way of example and not of limitation, ASUs described in any of the following U.S. patents can be used: 5,682,767, 5,901,577, 5,996,373, and 6,202,422 B1.

[0015] A typical air separation unit 100, shown in FIG. 1 can be configured such that filtered atmospheric air is brought into the plant via a filter 102, an air intake 104 with guide vanes, a main air compressor 106, a dryer 108, and a cooler 110. The dryer 108 can use molecular sieves that are regenerated using a stream of waste nitrogen from another component within the air separation unit. The cooler 110 can be a high efficiency main heat exchanger. The cool, dry, high pressure air can then be directed into the bottom of the high pressure cryogenic distillation column 120.

[0016] The bottom of the high pressure cryogenic distillation column 120 contains oxygen-rich liquid (called rich liquid) 122 that can be used as the feed 123 for the low-pressure cryogenic distillation column 130. Condensed, relatively pure nitrogen 124 is formed at the top of the high pressure cryogenic distillation column 120. The condensed, relatively pure nitrogen 124 can be used as reflux 126 for the high pressure cryogenic distillation column 120, reflux 128 for the low pressure cryogenic distillation column 130, and can be output as either liquid or gaseous nitrogen 125.

[0017] The bottom of the low pressure cryogenic distillation column 130 contains pure liquid oxygen 134, which may be drawn off as output from the ASU. Gaseous oxygen 136 within the low pressure cryogenic distillation column 130 can be drawn off directly above the liquid oxygen level. The top of the low pressure cryogenic distillation column 130 contains pure gaseous nitrogen 138, referred to as low-pressure nitrogen.

[0018] An air separation unit 100 may also include a crude argon column 140, which may be configured as a third cryogenic distillation column attached to the side of the low pressure cryogenic distillation column 130. The low pressure cryogenic distillation column 130 provides an argon-rich stream 132 to the bottom of the crude argon column 140. The crude argon column 140 washes oxygen out of the argon and produces a stream of crude argon 142 that is sent to a pure argon column 150. The pure argon column 150 strips away the remaining nitrogen to produce marketable liquid argon 152. Waste nitrogen 154 from the pure argon column may be used in the dryer 108, if desired.

[0019] As will be clear to one skilled in the art, many other configurations of air separations units may be formed, producing greater or fewer types of products.
Air separation units can include a plurality of field elements, such as pumps, compressors, guide vanes, and other devices. At a lowest level of regulatory control, the field elements of an ASU plant 100 illustrated in FIG. are controlled by traditional regulatory controllers such as proportional-integral-differential (PID) controllers, deadband controllers, gap controllers, or hand indicating controllers (HICs). The regulatory controllers regulate the field elements of the ASU plant with high-speed control algorithms (typically less than one second) at setpoints for the regulatory controllers. The setpoints for the regulatory controllers may be entered either by human operators or by another (e.g., higher level) controller, or both.

[0020] As an example, in FIG. 1, a regulatory controller 180 is used to control the guide vanes of the air intake 104 to adjust the flow of air into the high pressure cryogenic distillation column 120. The regulatory controller 180 may be any type of suitable controller, including a PID controller, a HIC controller, deadband controller, or a gap controller. In an exemplary embodiment, as illustrated in FIG. 1, the regulatory controller 180 is a PID controller.
For a single ASU, it is generally desirable to optimize the operation of the ASU to meet the following goals: (a) maintain the quality of the nitrogen and oxygen products

at a specified level (e.g., minimum purity required to meet contract specifications) while minimizing the waste nitrogen purity and crude argon nitrogen impurities; (b) maximize the product yield (e.g., maximize oxygen, nitrogen, and argon produced from the incoming air feed); (c) stabilize the process (e.g., adjust process conditions to maintain the ASU operation within process and equipment constraint limits, and minimize transient disturbances when the unit is being ramped to new feed or product targets); and (d) maximize the feed throughput for a given energy consumption (e.g., maximize the feed rate subject to equipment limits and product quality specifications). In a market-limited case (e.g., the demand is less than the maximum product yield of the ASU), the feed throughput is efficiently maintained at a lower than maximum level.

[0021] For a given product quality, it is generally desirable to maximize the product yield from the incoming feed air while minimizing the energy consumption of the ASU. Most of the operational cost of an ASU 100 is due to its energy consumption.

[0022] Figure 2 illustrates an exemplary embodiment of a network 200 of air separation units 210. A network 200 of air separation units includes at least two air separation units 210, and a pipeline 220 in fluid communication with the air separation units 210. The pipeline 220 can transport gases from the air separation units 210 to the customers 230. The network 200 also includes a control system 250 in control communication with the air separation units 210. Each air separation unit 210 has a plurality of field elements 212, such as pumps, compressors, guide vanes, and other devices.

[0023] The network 200 of air separation units may include some ASUs with greater or lesser efficiency. Further, each ASU can have a range of production levels at which it is most efficient, and other production levels at which it is less efficient. To optimize the network performance, some ASUs may be operated at sub-optimal production levels, that is, at production levels at which they are not most efficient. For example, it might be desirable to operate several ASUs at production levels above their most efficient ranges and to shut down a less efficient plant in the network.

[0024] In exemplary embodiment of the invention shown in FIG 3, the control system 250 is in control communication with the at least two air separation units in the network. The control system 250 can include a supervisory level controller 320 and a receiver 310 for receiving inputs from the at least two air separation units 210 in the network 200. The inputs may include, but are not limited to, current plant production data, current plant capacity and production limitation data, and advanced process controller health status and limitation data. The supervisory level controller 320 can generate data representative of a combined production target level and a combined network energy usage level for the air separation units 210 in the network 200. The control system 250 can be used to optimize the performance of the network 200, to ensure the ASUs 210 produce the required product yield at the least cost (lowest combined energy usage level).

In an exemplary embodiment of the invention, the supervisory level controller 320 receives a production level requirement for the network of air separation units, and generates a production target level for each ASU.

[0025] The production level requirement for the network of air separation units, and, in general, data which is representative of a network production target level and a network energy usage level, can be generated at the operation control center (OCC), and can be based on the current cumulative production from the air separation units, on current and predicted customer consumption, and on the hydraulic profile of the pipeline network itself. With the network production requirement known, the control system can determine the optimal individual production level targets required of the network ASUs.

[0026] In an exemplary embodiment, the supervisory controller 320 includes logic, software programs, and/or expert systems to find the optimum real-time production level target for each ASU. Examples of commercially software programs suitable for controller 320 include, but are not limited to, SynerGEE, a pipeline hydraulic optimizer available from Stoner Associates, Carlyle, Pennsylvania, Visual Mesa, available from Nelson & Roseme, Walnut Creek, California, and G2, available from and Gensym Corporation, of Burlington, Massachusetts.

[0027] At the ASU level, when the control system 250 communicates a new production target level to an ASU 210, the production level of the ASU 210 is changed until it is about equal to the production target level for that ASU 210 generated by the supervisory level controller 320. The production level of an ASU may be changed by any type of suitable adjustment means. Ideally, the production level of the ASU 210 is adjusted in a way which optimizes the ASU plant performance, that is, it maximizes the product recovery, maintains the product quality, and minimizes the energy consumption of the ASU, during the period in which the production level of the ASU is ramped to the desired production level. Generally, it is desirable to ramp to the new production target as fast possible in order to achieve the new network optimum in the minimum elapsed time. Once the new production target is met, it is desirable to maintain this new production level in the most efficient manner possible (e.g., with minimal local energy consumption).

[0028] In an exemplary embodiment, the adjustment means is an advanced process controller 330, which can optimize the operation of an ASU during ramping of the production level, and during operation at or near the production target level. To achieve this, the advanced process controller 330 is used to set a setpoint for at least one controller for a field element within the ASU. Referring again to FIG. 1, as an example, the advanced process controller 330 could set a setpoint for the PID

controller 180 that regulates the quantity of feed air into the cryogenic high pressure distillation column 120. An advanced process controller 330 could also set a setpoint for another type of controller within the ASU, for example, an advanced regulatory controller 340 shown in FIG. 3 and FIG. 1.

[0029] The advanced process controller 330 can by any type of controller suitable for setting a setpoint. One type of advanced process controller 330 which would be suitable is an advanced feedforward controller. An advanced feedforward controller is a pseudo cascade controller where the setpoint is the result of the calculated feedforward value biased by a feedback controller. The advanced feedforward controller can be a collection of multiple-input/single-output (MISO) controllers.

[0030] Another type of advanced process controller 330 which could be used is a multivariable predictive controller (MVPC). Like an advanced feedforward controller, the multivariable predictive controller writes to setpoints or targets, rather than directly manipulating outputs to regulatory controllers (final control devices). The multivariable predictive controller can be a multiple-input/multiple-output (MIMO) system, which incorporates both feedback and feedforward type control actions.

[0031] A multivariable predictive controller identifies relationships between control (or constraint) variables and manipulated variables (changes in setpoints which affect the control variables), then optimizes the process using the identified relationship (or model) between the control variables and the manipulated variables. Repeatable process disturbances can also be included by identifying the relationship between disturbance variables and the control variables. Responses to process disturbances are modeled by first perturbing the independent process variables (manipulated variables) (e.g., the feed rate and reflux rate), measuring the response of the dependent variables (control variables) (e.g., product qualities and column temperatures), and developing models of responses to different process disturbance levels.

[0032] An example of a suitable multivariable predictive controller is a goal maximizing controller available from Intelligent Optimization, Inc. of Houston, Texas, under the trade name GMaxC. To initially test and set up GMaxC controller, the independent process variables are perturbed by approximately ±3% to study their interactions with dependent variables. Typically, it takes about 12 hours for each set of five independent variables, with the total plant testing expected to take about 24 to 36 hours. If historical data is sufficient to identify dynamic models, minimal plant testing will be required.

[0033] MVPC controllers are often used for processes involving many variables with multiple interactions, and significant response delays between inputs and outputs. Examples of control variables to which an MVPC can be applied include, but are not limited to, reflux flow rates, main dry air flow rates, crude argon production rate, liquid nitrogen production rate, expander inlet flow rate, gas oxygen production rate. An advantage of a multivariable predictive controller is that it requires very little human intervention in it mission of optimizing and stabilizing plant operation.

[0034] The advanced process controllers can also be connected to or interfaced with an ASU's Distributed Control System (DCS). The DCS provides interfaces between field elements and ASU controllers, and can provide the plant operators with continuous information about the operation of the ASU's controllers and field elements. The DCS also provides a means for operators to make changes to field elements within the plant. Examples of suitable distributed control systems include, but are not limited to, the Foxboro I/A, Honeywell TDC-3000, Fisher-Rosemount DeltaV and RS3, Siemens-Moore APACS+ and PCS-7, Yokagawa CS1000/3000, and Bailey Infi/Net-90.

[0035] In another exemplary embodiment, both an advanced feedforward controller and a multivariable predictive controller are used for advanced process control. The advanced feedforward controller and the multivariable predictive controller share similar goals, that is, to optimize the performance of an ASU, especially during ramping of the ASU production level. A combined APC strategy, that is, one using both a multivariable predictive controllers and an advanced feedforward controller, can minimize implementation time and simplify APC tuning for some applications.

[0036] Advanced process controllers 330 can have shutoff logic and/or devices to allow them to be shut off by network or plant operators for various reasons, such as, for example, to allow direct control of the plant by the plant operators, or if the advanced process controllers are not working well. Unless the advanced process controllers 330 are operational, the efficiencies in plant operation which result from their use will not normally be realized. Therefore, in another exemplary embodiment, the control system 250 also can include a monitoring system 360 to monitor the status of the advanced process controllers 330. The monitoring system can provide an indication that an advanced process controller 330 is not in service, or is only partially operational, and is in need of attention. The monitoring system can identify to what extent an advanced process controller is operational (e.g., identify an APC service factor). In an exemplary embodiment, the monitoring system 360 also schedules required maintenance of the advanced process controllers 330 in the ASUs. By adding a monitoring system 360, the percentage of manipulated variables controlled by advanced process controllers will normally increase, indicating an improvement in system performance.

[0037] In another exemplary embodiment, a control system 250 includes advanced regulatory controllers in the at least two air separation units of the network. An advanced regulatory controller 340 can write setpoints directly to the regulatory controllers (final control ele-

ments) for the field elements 370 within the air separation units.

[0038] The advanced regulatory controllers 340 are useful for critical control loops such as, for example, highly interactive, integrating liquid levels, which can be difficult to control using multivariable predictive controllers due to their slower response times. In addition, the advanced regulatory controllers are useful for fast load changes. As an example, referring again to FIG. 1, an advanced regulatory controller 340 can be used to control the flow rate of the rich liquid reflux 126 in the high pressure cryogenic column 120 so it would remain as constant as possible, even during plant ramping and other perturbations.

[0039] The advanced regulatory controllers 340 typically use more complicated control methods than traditional regulatory controllers such as PID controllers, but that have a faster execution frequency (e.g., less than five seconds) than the MVPC controllers. Further, the advanced regulatory control layer (the set of advanced regulatory controllers 340 for an ASU, including adaptive controllers) is important for stable ASU operations on critical, hard-to-tune loops where traditional regulatory controllers (e.g., PID controllers) must be constantly adjusted for various operational modes. The advanced regulatory control layer is also useful for critical control loops such as highly interactive, integrating levels, which can be difficult to control with traditional or multivariable predictive control (MVPC), and is crucial for fast load changes.

[0040] In an exemplary embodiment, the advanced controller is a model free adaptive controller. An exemplary example of a suitable model free adaptive controller is the model free adaptive controller described in U. S. Patent No. 6,055,524, issued to Cheng, an embodiment of which is available from General Cybernation Group, Inc., in Rancho Cordova, California, under the trade name CyboCon Model-Free Adaptive Controller. In an alternative embodiment, the advanced regulatory controller can be a model-based adaptive controller. An example of a suitable model-based adaptive controller is the model-based adaptive controller available from Adaptive Resources, Lawrence, PA, under the trade name QuickStudy Adaptive Controller.

Use of an advanced regulatory controller, MVPC, and AFF appears to increase stability and load change speed in an ASU.

[0041] The control system illustrated in FIG. 3 thus includes a supervisory controller, and can include various additional controllers or control layers within each ASU. Addition of a supervisory controller and the underlying advance process control and advance regulatory control layers to a network of ASUs will normally lower plant operations staffing costs. For example, a network of ASUs with supervisory controls and advance process controllers may operate 24 hours per day, and require human operators to be present only 40 hours each week. Additionally, the operators, while on duty at the plant, can focus significantly less time on plant operations and more time on other activities like routine plant maintenance, housekeeping, paperwork, etc., thus indirectly reducing staffing costs further. Referring again to the network control hierarchy shown in FIG. 3, the cost to implement each layer of controllers typically decreases, and the benefits increase, for each properly implemented successively higher layer.

[0042] It will be appreciated by those skilled in the art that the present invention can be embodied in other specific forms without departing from the spirit or essential characteristics thereof, and that the invention is not limited to the specific embodiments described herein. The presently disclosed embodiments are therefore considered in all respects to be illustrative and not restrictive, and the scope of the invention is to be determined by reference to the appended claims. Each of the aforementioned published documents are incorporated by reference herein in its entirety.

Claims

1. A method of automatically setting a target production level for at least one air separation unit in a network of air separation units, each air separation unit including a plurality of field elements and at least one regulatory controller associated with one of the field elements, and having an energy usage level corresponding to a level of production, comprising:

    receiving a production level requirement for the network of air separation units, and
    generating a production target level for at least one of the air separation units which minimizes the sum of the energy usage levels.

2. A method as in claim 1, further comprising:
    changing the level of production for one of the at least one air separation units until it is about equal to the generated production target level for the air separation unit.

3. A method as in claim 2, wherein the changing the production level comprises:
    using an advanced process controller to set a setpoint associated with at least one of the plurality of field elements.

4. A method as in claim 3, wherein the advanced process controller is an advanced feedforward controller.

5. A method as in claim 3, wherein the advanced process controller controller is an multivariable predictive controller.

6. A method as in claim 3, wherein the advanced proc-

ess controller includes an advanced feedforward controller and a multivariable predictive controller.

7. A method as in claim 3, further comprising: monitoring the advanced process controller to determine whether is operational.

8. A method as in claim 7, further comprising: identifying an advanced process controller if it is non-operational or partially-operational.

9. A method as in claim 8, further comprising: determining an advance process controller service factor.

10. A method as in claim 3, further comprising: controlling at least one of a plurality of field elements in an air separation unit.

11. A method as in claim 10, wherein the controlling includes using a model based adaptive controller to control the field element.

12. A method as in claim 10, wherein the controlling includes using a model free adaptive controller to control the field element.

13. A method as in claim 10, wherein the controlling includes using a regulatory controller to control the field element.

14. A control system for automatically setting the target production level for at least one air separation unit in a network of air separation units, each air separation unit including a plurality of field elements and having at least one production level and an energy usage level corresponding to the production level, comprising:

a receiver for receiving inputs from the air separation units; and
a supervisory controller for generating a production target level for at least one of the air separation units.

15. A control system as in claim 14, wherein the inputs include the energy usage levels and the production levels of the air separation units.

16. A control system as in claim 14, further comprising: an advanced process controller for changing the production level of one of the at least one air separation units until it is about equal to the generated production target level for the air separation unit.

17. A control system as in claim 16, wherein the advanced process controller generates a setpoint associated with at least one of the plurality of field elements.

18. A control system as in claim 17, wherein the advanced process controller is an advanced feedforward controller.

19. A control system as in claim 17, wherein the advanced process controller is an multivariable predictive controller.

20. A control system as in claim 17, wherein the advanced process controller includes an advanced feedforward controller and a multivariable predictive controller.

21. A control system as in claim 17, further comprising a monitoring system for monitoring the advanced process controller.

22. A control system as in claim 17, further comprising: an advanced regulatory controller for regulating at least one of the plurality of field elements in an air separation unit.

23. A control system as in claim 22, wherein the advanced regulatory controller is a model-based adaptive controller.

24. A control system as in claim 22, wherein the advanced regulatory controller is a model free adaptive controller.

25. A control system as in claim 22, further comprising:

a regulatory controller for controlling a field element,
wherein said regulatory controller is a proportional plus integral plus derivative controller, a gap controller, a deadband controller, or a hand indicating controller.

26. A network of air separation units, comprising:

at least two air separation units, each air separation unit including a plurality of field elements and having at least one production level and an energy usage level corresponding to the production level;
a pipeline in fluid communication with the at least two air separation units;
a control system for automatically setting the target production level for the at least two air separation units, the control system in control communication with the at least two air separation units and including
a receiver for receiving inputs from the at least two air separation units, and

a supervisory controller for generating data representative of a network production target level and a network energy usage level for the at least two air separation units.

27. A network as in Claim 26, further comprising:

an Operational Control Center for generating a network production level target, and wherein data includes a production target level for at least one of the air separation units.

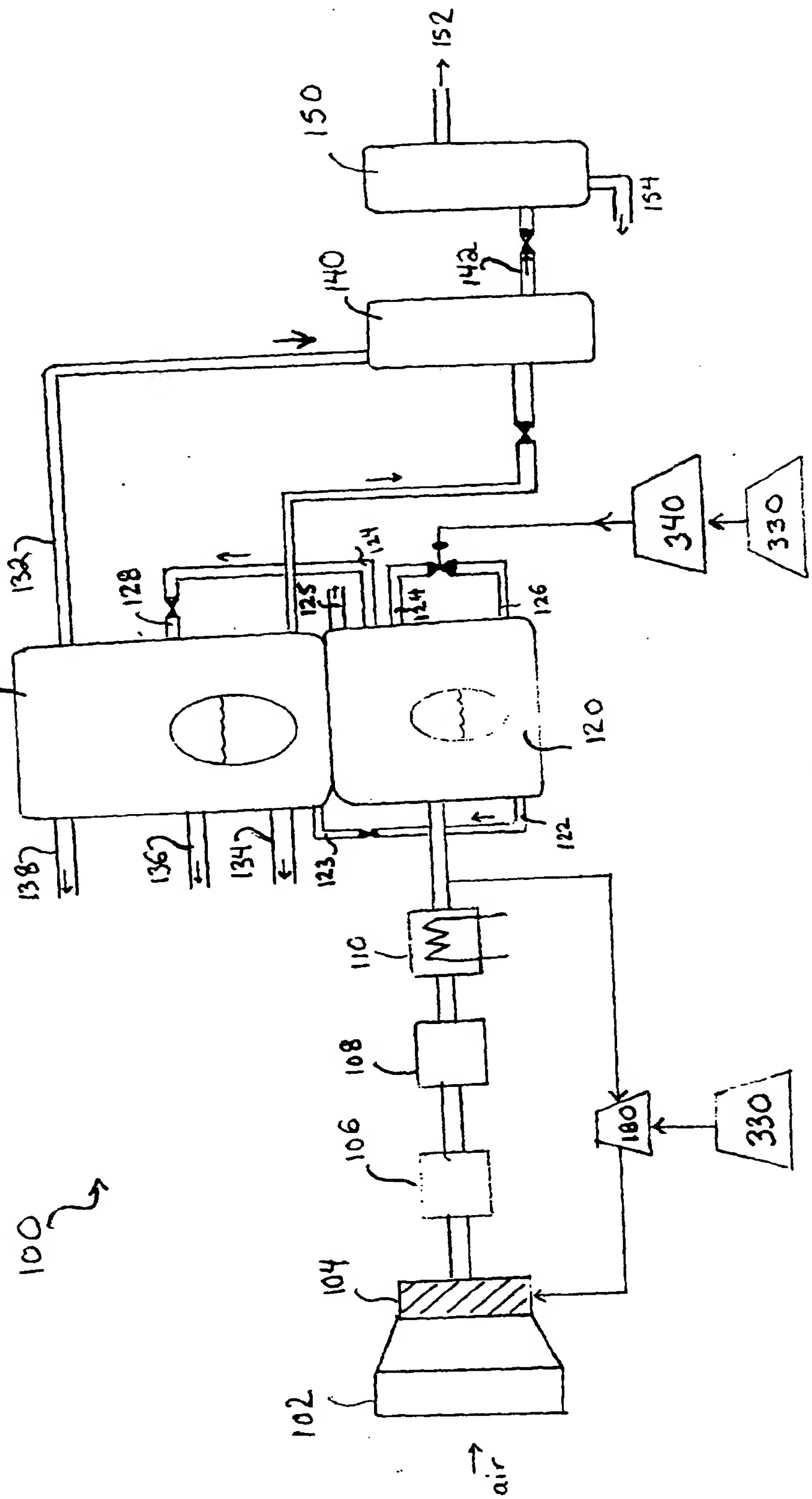
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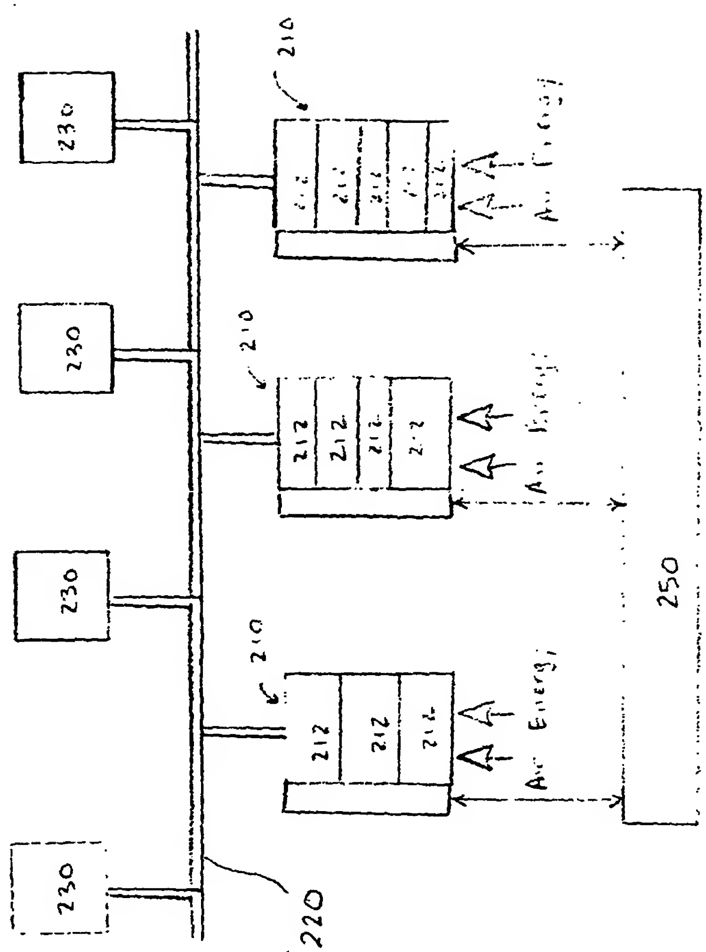
FIG. 1

FIG. 2



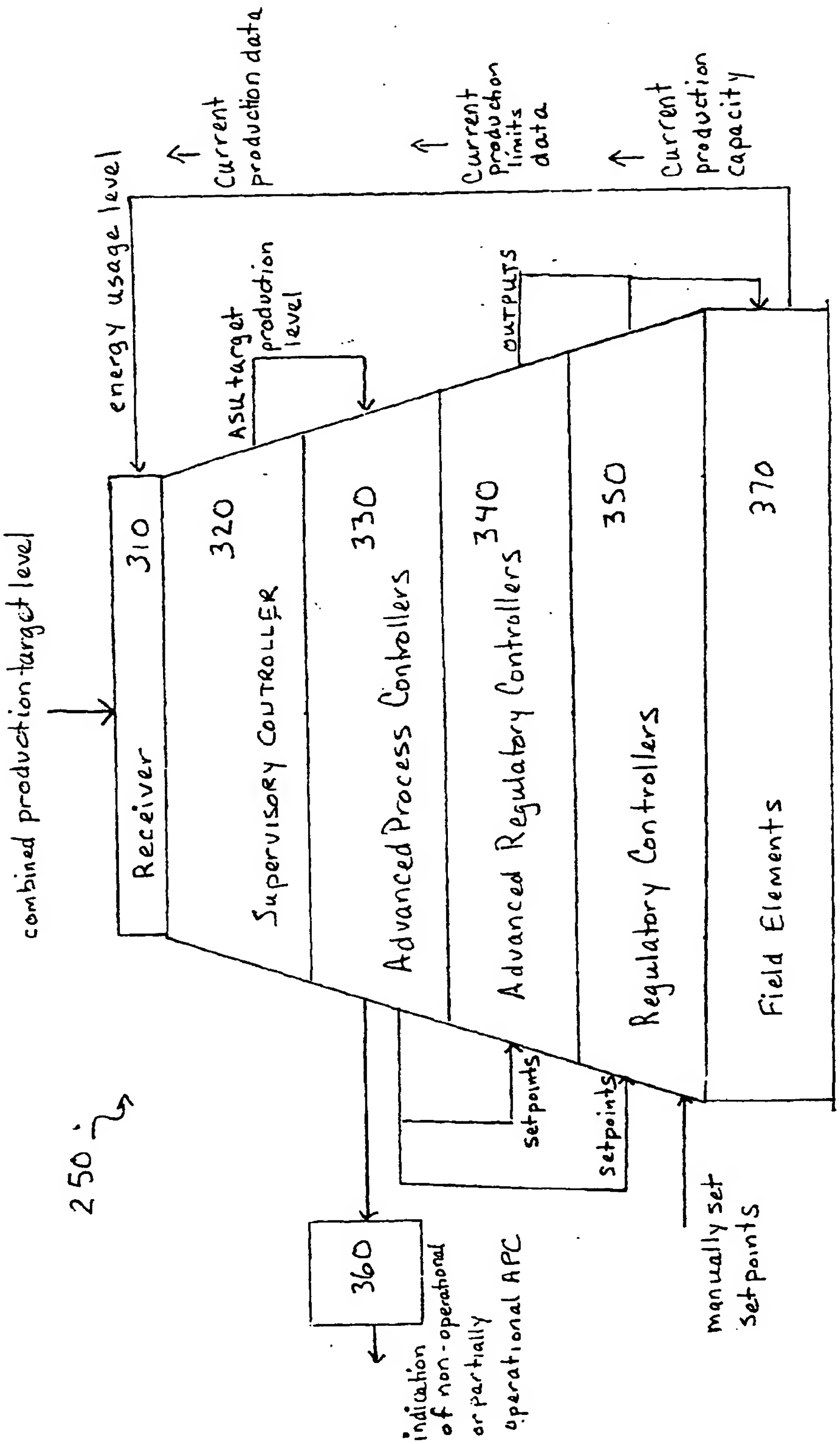

combined production target level
Receiver
310
Supervisory CONTROLLER
320
Advanced Process Controllers
330
Advanced Regulatory Controllers
340
Regulatory Controllers
350
Field Elements
370
energy usage level
Current production data
ASU target production level
OUTPUTS
Current production limits data
Current production capacity
setpoints
setpoints
manually set setpoints
360
indication of non-operational or partially operational APC
250

FIG. 3

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(54) **Automatic control system and method for air separation units**

(57) A method for automatically setting a target production level for at least one air separation unit in a network of air separation units. Each air separation unit has a plurality of field elements (370) and at least one regulatory controller (350) associated with one of the field elements (370), and has an energy usage level corresponding to a level of production. The method includes receiving a production level requirement for the network of air separation units and generating a production target level for at least one of the air separation units which minimizes and/or optimizes the sum of the ASU energy usage levels. The ASUs then can automatically ramp the plant production to the appropriate production target levels via the use of advanced process control (330) (multivariable process controllers and/or advanced feedforward controllers), advanced regulatory control (340), and regulatory control (350) means. The control system (250) includes a receiver (310) for receiving inputs from the at least two air separation units, and a supervisory controller (320) which generates production target levels for sending to each air separation unit, the production target levels being representative of a network production target level and a network energy usage level.

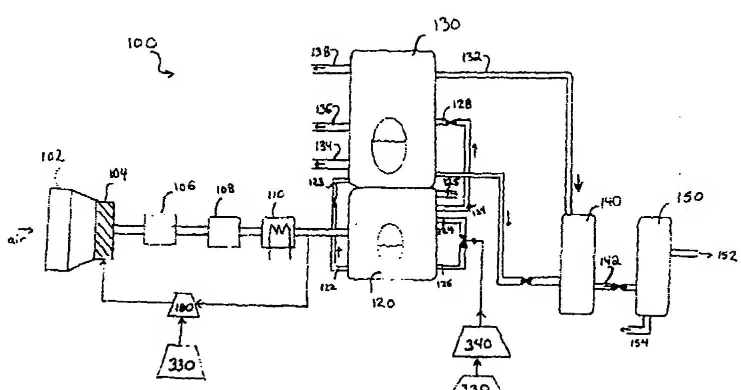

FIG. 1

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Application Number
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	14 August 2002	Göritz, D

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Process and Facility with Particularly High Availability

p. 276-279 = (7)   p d. 05-1997

In a process for the low-temperature separation of air, feed air is compressed and purified in a hot section. The compressed and purified air is introduced into a cold section which has a main heat-exchange section and a rectification system. The rectification system has at least one rectifying column. The air is cooled in the main heat-exchange section and introduced into the rectification system. At least one oxygen, nitrogen or argon product is recovered in the rectification system. However, the process can also be used analogously for separating other gas mixtures.

In processes of this kind, large amounts of constituents of air, such as nitrogen, oxygen and/or argon, are frequently recovered. If such a plant breaks down, considerable losses are frequently incurred due to the loss of product. It is known to install a double configuration of individual apparatuses, for example a molecular-sieving station for purifying feed air, in order to achieve a certain degree of protection at least against them breaking down individually. However, this only increases the availability of an air separation plant to a limited extent.

Therefore, in a first variant of the process, the hot section has two trains which are independent of one another, each for one stream of feed air, in which case, in normal operation, a first feed-air stream is compressed and purified in a first hot train and a second feed-air stream is compressed and purified in a second hot train, independently of the first feed-air stream. In a second variant of the process, the main heat-exchange section has two trains which are independent of one another, each for one stream of feed air, in which case, in normal operation, a first feed-air stream is cooled in a first main heat-exchange section train and a second feed-air stream is cooled in a second main heat-exchange section train, independently of the first feed-air stream.

The underlying principle of both variants is to provide entire process sections in twofold design and independently of one another, specifically at least the air compression and the purification in one case and the heat-exchanger configuration in the other case. Independence is to be understood here as meaning that, in normal operation, there is no direct exchange of process fractions between the two trains. What this means for the device is that preferably, although not necessarily, there are no corresponding direct flow connections between the two trains; if they are in fact present, devices have to be provided which close off these connections in normal operation of the plant. Preferably, the apparatuses and process configuration of the pair of trains are identical, and can therefore be produced cost-effectively. If precisely two trains are present, then in each case half of the feed air and the other process fractions flows through one train. Naturally, it is possible in principle to provide more than two trains for the hot section and/or the main heat-exchange section.

While in normal operation all the feed air, and when one of the two trains has been shut down the remaining feed air, is introduced into the main column, in the event of failure of the main column, the air from one of the two trains can be fed into the redundancy column and production can be continued there. Depending on product availability requirements, it may be expedient to shut down further columns situated downstream of the main column, for example columns used for recovering noble gas.

The rectification system may have one or more columns for the recovery of argon, in which case the, normally one, argon-containing fraction from the main column is introduced into this column or into one of these columns. In the event of interruption to the operation of the main column, these columns may be cut back; in this case, there is no need for any connection between the redundancy column and the column or columns for the recovery of argon.

If the main heat-exchange section has machines, such as expansion turbines and/or pumps, it is beneficial also to provide them in a twofold design and to assign one to each of the trains.

Particularly when generating cold by expanding a process fraction in a manner performing work, it is beneficial if the expansion in a manner performing work of a first stream of the process fraction is carried out in the first main heat-exchange section train and the expansion in a manner performing work of a second stream of the process fraction is carried out in the second main heat-exchange section train. In a similar manner, when a liquid fraction is brought to an elevated pressure by means of a pump (internal compression), it is possible to increase the pressure of a first stream of the liquid fraction in the first main heat-exchange section train and to increase the pressure of a second stream of the liquid fraction in the second main heat-exchange section train. Naturally, one or more further work-performing expansions and/or one or more further pressure increases in the liquid state may likewise be integrated into the twofold design of the main heat-exchange section.

The process and the corresponding facility are not restricted in principle to the separation of air, but can also be used in other gas-separation plants in which a gas mixture is separated by rectification, e.g. at low temperature.

The appended drawing shows a diagrammatic representation of an exemplary embodiment of the process.

Downstream of a filter 101 and the compression 102, feed air 100, 103 is precooled in a precooling system 104 in direct heat exchange with cooling water 105, 106. The precooled air 107 is purified in the molecular-sieving station 108, in particular purified of water, carbon dioxide and certain hydrocarbons. The purified air 109 of the first train A is divided into a first and a second part stream 110, 112. The first part stream 110 is fed directly into the cold section, which is enclosed in the cold box 111. The second part stream of air 112 is additionally compressed in a booster compressor 113 and, following removal of the heat of compression in the

Normal operation is understood here to mean the operating situation in which all machines are operated without disruption, or virtually without disruption. In the event of disruption, at least one of the machines or one of the apparatuses in one of the trains is out of use, for example due to scheduled maintenance or due to a defect. In this case, that train in which the interruption occurs is shut down completely. The plant can then continue to be operated with the aid of the remaining train, at least with half the throughput of air. In this case, the operation of process sections situated downstream of the two-train configuration can be altered, for example such that the most important product is generated in a relatively greater amount. Actually shutting down the defective train can be achieved in a simple manner by means of control technology; in particular, it is significantly less complex than when shutting down a single one of doubly configured apparatuses. Moreover, maintenance work can be performed on all apparatuses of the train which has been shut down.

In the first variant of the process, the precooling and/or optional booster compression of the air downstream of the purification may additionally be integrated in the two-train configuration of the hot section.

A combination of the two variants makes it possible to achieve very high availability. In normal operation, the first feed-air stream, which exits the first hot train, is introduced into the first main heat-exchange section train, and the second feed-air stream, which exits the second hot train, enters the second main heat-exchange section train. This results in two independent trains which comprise a large number or even all of the process steps upstream of the rectification system and thus provide protection against complete failure.

Furthermore, it is possible, with comparatively little effort, to take precautions for the failure of the most important rectifying column by providing the rectification system with a main column and a redundancy column, in which case, in normal operation, the first and second feed-air streams are introduced into the main column and, in the event of interruption to operation of the main column, one of the two feed-air streams is introduced into the redundancy column.

The main column is designed, for example, as a single column, but more frequently as a double column. The equipment of the redundancy column may be relatively simple compared to the main column, for example with regard to its material-exchange elements, its cross-section and its control technology, since it is only designed for part (generally half) of the quantity of air, is operated for only a limited period and therefore does not have to provide an optimum product yield. In the case of a double column, it is also possible, for example, to dispense with additional parts, such as a supercooling countercurrent heat exchanger. The redundancy column is preferably arranged inside the same cold box as another column of the rectification system, so that it is at low temperature even during normal operation of the plant, i.e. when it is not being operated itself.

aftercooler 114, is likewise fed to the cold section (115). One part 116 is cooled in a heat exchanger 118 and at least partially, preferably completely or essentially completely, liquefied against vaporizing product streams and fed via line 119 in the direction of the rectification system. Another part of the second part stream of air 115 is removed from the heat exchanger 118 at an intermediate temperature and is expanded in a manner performing work in the turbine 121 (the turbine 121 may also be operated with any other process fraction, e.g. with nitrogen). The first part stream of air 110 is cooled in a further heat exchanger 123. The two heat-exchanger blocks 118 and 123, together with the turbine and the associated piping, form the first train A of the main heat-exchange section; they are interlinked by a compensation stream, which is formed by part of the first air stream 110. The air which has been expanded in a manner performing work, the cooled compensation stream and the remaining first part stream 124 from the train A are fed to the rectification system together.

The second train B of the hot section and of the main heat-exchange section is identical to the first train A with regard to its structure and design. Corresponding reference numerals in the two trains differ only by their first number.

The cold box 50 surrounds the cold section, of which the drawing only shows the apparatuses and machines. Each train has its own heat exchangers 118/123, 218/223, separate turbines 121, 221 and separate internal compression pumps 140/141, 240/241, in order to increase the pressure in product (oxygen and/or nitrogen) obtained in liquid form. The cold box contains a number of partitioning walls, so that it has a total of four chambers which can be emptied independently of one another and can thus be made accessible for maintenance or repair work:

- 150 first train of the main heat-exchange section
- 250 second train of the main heat-exchange section
- 350 main column 301
- 351 redundancy column 320 and argon recovery system with crude argon column 330a, 330b and pure argon column 336

Instead of the partitioning walls, the individual chambers of the cold box may also be completely separate from one another.

The liquid feed-air streams and the combined gaseous feed-air streams from the two trains of the main heat-exchange section are combined upstream of the rectification system and are introduced into the high-pressure column of a main column 301 designed as a double column. The high-pressure column is in a heat-exchanging relationship with the low-pressure column of the double column 301 via a main condenser. Bottom liquid and liquid nitrogen from an intermediate location situated somewhat below the head are drawn off from the high-pressure column, are supercooled in a countercurrent heat exchanger and are at least in part fed into the low-pressure column. Nitrogen liquefied in the main condenser is in part fed through the countercurrent heat exchanger 308, drawn off as liquid product (LIN) (410) and

fed to the nitrogen tank 401 (410); the other part is divided between the first train A and the second train B (228) of the main heat-exchange section and is in each case internally compressed by means of a pump 140, 240.

Impure nitrogen and a small amount of gaseous oxygen as residual gas and liquid oxygen as product which is to be internally compressed (pumps 141, 241) are removed from the low-pressure column and divided between the two trains of the main heat-exchange section.

The pumps are arranged downstream of the division between the two trains and in each case belong to one train of the main heat-exchange section. Each of the liquid lines thus comprises its own independent pump 140, 240, 141, 241 (one pump each for each internally compressed product in each train).

The preheating and possible volatilization of the products which are to be drawn off in gas form in train A are described below. The two liquid products are volatilized and preheated in the heat exchanger 118 and finally discharged as gaseous high-pressure products (HP-GAN and GOX). Part of the liquid nitrogen may be throttled off and, following preheating in 118, may be removed as low-pressure product (LP-GAN). The residual gas is preheated in the heat-exchanger blocks 118 and 123 and part is added to the low-pressure nitrogen LP-GAN and the other part used to regenerate the purification device 108 and/or to cool cooling water in a cooling tower.

Like the main column 301, the redundancy column 320 is designed as a double column (high-pressure column, low-pressure column, main condenser), but is significantly more simple. Thus, in contrast to the main column, which is provided at least in the upper part with ordered packing, it merely contains conventional rectifier plates which are arranged spaced relatively close together. There is only a single air feed line, which can be connected exclusively to the line for gaseous air of the first train A of the main heat-exchange section. The number of product lines is limited to three: gaseous nitrogen from the low-pressure column, liquid nitrogen from the high-pressure column and liquid oxygen from the low-pressure column. Each of these product lines can be connected to the first train A of the main heat-exchange section. Only a bottom liquid line and a liquid nitrogen line are present at internal connections between high-pressure column and low-pressure column; a countercurrent heat exchanger is dispensed with.

Crude argon is obtained in a known manner. The crude argon column, comprising two sections 330a and 330b, moreover has an additional section beneath the feed from the low-pressure column of the main column, which additional section serves to recover high-purity oxygen and has a bottom evaporator operated with nitrogen from the high-pressure column. The high-purity oxygen is introduced in liquid form into a tank 400 (line 409). The pure argon column 336 serves for argon-nitrogen separation. Pure liquid argon is fed into the liquid argon tank 402 via line 412.

In normal operation, the connections between the first train of the main heat-exchange section and the redundancy

column are closed, and both trains, the main column and the argon recovery system are operated as designed.

The text below will explain two shut-off scenarios, in order to illustrate the functioning of the process and of the device in the event of failure of one or more apparatuses with reference to concrete examples.

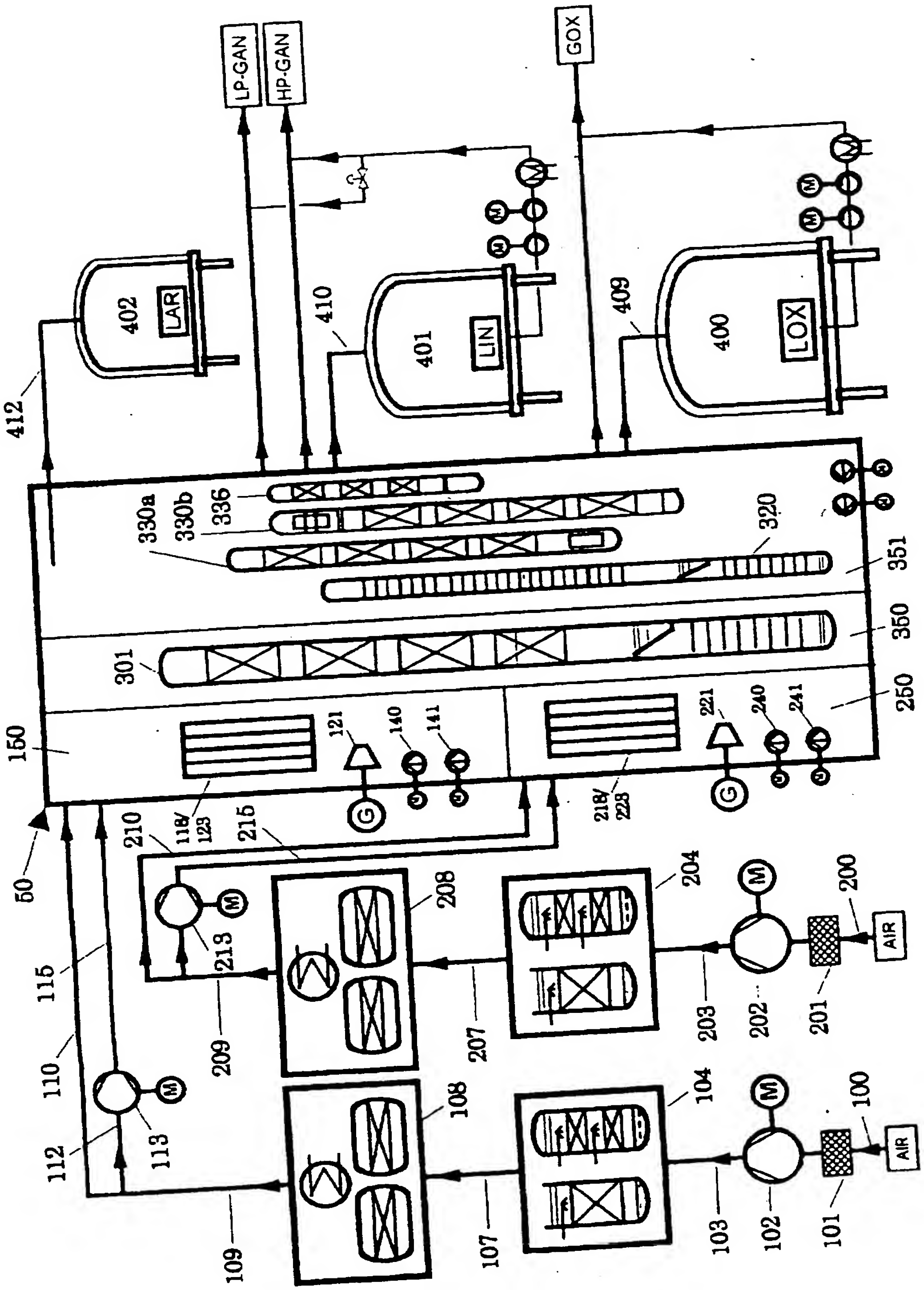
Scenario 1:

If the air compressor 102 of the first train of the hot section fails, the remaining part of the first train, comprising the precooling 107, the purification 108, the booster compressor 113 and the first train of the main heat-exchange section (region 150 of the cold box) is also shut down. The amount of air processed in the main column 301 falls to 50 % compared to normal operation, but production can be continued at this level. Switching over can be performed either manually or by the process control system.

In the event of the breakdown of one or more other apparatuses in one of the two trains, the operation of the plant can be switched over in a similar manner.

Scenario 2:

Even if the main column 301 fails, the plant can continue to be operated under part load. In that ase, all connections between the main heat-exchange section and the main column are closed, the complete second train of the hot section and of the main heat-exchange section and the argon recovery system 330, 336 are shut down and the connections between the first train of the main heat-exchange section and the redundancy column 320 are opened. The redundancy column is still able to supply the entire amount of gaseous compressed nitrogen obtained during normal operation, but with a significantly reduced amount and purity of oxygen. By virtue of having its own cold box section 350, the main column 301 is accessible despite the continued operation of the plant and can be repaired. After completion of work, the main column can be cooled down using the restarted second train; the columns for the recovery of argon which have been shut down remain at low temperature anyway, by virtue of the cold box 351 which they share with the operating redundancy column 320. As a result, the main column and argon recovery system can be restarted in a particularly expedient manner.



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